Estimation of parameters of plasma on the data on shock wave passage through plasma

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Introduction

The report is devoted to an opportunity of use of measurement results of various shock waves parameters for an estimation of parameters of plasma through which the shock wave is distributed. The purpose of the report is discussion of various experimental situations in which the data of the measurements which have been carried out by different methods, will allow to make representation about a condition of plasma (or spatial heterogeneity of temperature (density), created by other method). Realization is possible and estimations in "opposite" direction - the knowledge of parameters of plasma allows to estimate characteristics of a shock wave going through it.

Theoretical basis of a method

The substantive provisions used at calculation of speed of a shock wave, are given in work [1]. In brief they are reduced to the following. From results of work [2] the system of the equations follows

$$\frac{\partial x(t)}{\partial t} = a(x(t)) + a_0 \frac{f_2(x(t))}{2},$$
$$\frac{\partial\left(tf_2(x(t))\right)}{\partial t} = \frac{a_0 f_2(x(t))}{2a(x(t))}$$

(1)

where x - spatial coordinate, t - time, $f_2(t)$ - the function describing the initial form of indignation of a shock wave [2]. If spatial heterogeneity is caused by non-uniform distribution of temperature (or density) at constant pressure, than $a(x) = a(T(x)) = \sqrt{\gamma RT(x)}$ - speed of a sound in a point x, R - gas constant, $a_0 = a(T_0) = const$, T_0 - constant temperature outside of spatial heterogeneity area, $T(x)$ - the distribution of temperature determining the form of spatial heterogeneity, γ - adiabatic index.

The solution of system (1) for movement in a homogeneous environment gives a line of the simple formulas describing process of shock wave change. For practically important case rectangular distributions of temperature ($T(x)=T$ at $x_p > x \le x_f$, $T(x)=T_0$ at $x \le x_p$, $x > x_f$) the system of the equations (1) is solved precisely.

Generally the time at which the shock wave passes the distance between two points of registration (from x_b up to x_e), is defined by the formula

$$t_{be}(T)=\int_{x_b}^{x_e}\frac{dx}{V(x,T)}=t(x_e,T)-t(x_b,T), \qquad (2)$$

Value of the maximal temperature in the field of spatial heterogeneity it is possible to estimate not only on the data on change of speed or time of passage of a shock wave, but also on change of relative size of a registered signal (fig. 1 of work [3] and similar figures of work [5]). Reduction of size of the signal registered by a photodetector, is determined, on the one hand, by decrease of density in the field of the raised temperature ($\rho/\rho_0=T_0/T$, $T>T_0$), and, on the other hand, fall of local Mach number.

Definition of temperature of plasma on the measured parameters of a shock wave

Enough full information on conditions and results of the experiment is given in D.Van Wie with employees works [3,4]. In these works with the help of two lasers the time of a shock wave passage between two points of registration was registered. Measurements were carried out in air at pressure 1.6 and 10 Torr. The shock wave passed through plasma of the air discharge, and the direction of an applied electric field was perpendicular to a direction of shock wave distribution. The discharge might settle down in various sites of the working chamber. The characteristic kind of oscillograms on which time of passage of a shock wave between points of supervision is defined, is given on fig. 1 [3]. Having substituted time of movement in homogeneous (without plasma) environment $t=0.00055$ s, we shall define Mach number directly in the location of diaphragm $M_0=2.88$, that coincides with the data of works [3,4]. Then it is possible to calculate for the control the time of movement of a shock wave at nonzero currents, using for definition of temperature the formulas received from equality (2). The wall temperature of the digit chamber in works [3,4] was not measured, therefore we select the wall temperature from an estimation of the capacity, put in the discharge. On fig. 2a results of passing time calculation are given by a continuous curve at $c=1.7$, and dot curves correspond $c=1.6$ (the bottom curve) and $c=1.8$ (the top curve) (the wall temperature $T_b \approx cT_0$). The dotted curve is designed at $c_b=1/2$ and $T \approx (T+T_0)c_b\varphi$. For calculation of the points marked by squares, the temperature received on experimentally measured relative amplitudes of a signal. Dependences of temperature on a current (fig. 2b) are determined from the decision of the equation $t_{be}(T, M_0) = (t_{be})_{exp}$. Apparently, the estimations of temperature received on relative amplitude of a signal, are less exact, than definition of temperature on time measurements.

On fig. 3a the example of calculation of a shock wave movement speed as function of coordinate (a continuous curve, $T = 473K$). The dot-dash line shows the result at $T = T_0 = 300K$, i.e. in absence of thermal heterogeneity. The difference of these curves gives a gain of speed in a point of supervision x_e due to influence of thermal heterogeneity (fig. 3b). Authors of work [6] have obtained data about passage of a shock wave to plasma of argon (fig. 4a) and nitrogen (fig. 4b). In this work oscillograms is using the time measurement (which kind is similar given on fig. 1). It is obvious, that in this case estimations of temperature on time of shock wave passage have the same accuracy approximately, as estimations on signal amplitude.

In work [6] distributions of shock wave speed on coordinate are measured at various initial shock wave speeds at passage by a shock wave of heterogeneity with linearly varying density $\rho_1(x)/\rho_{10} \approx 0.2 + 0.8(x - x_p)/(x_f - x_p)$ (this dependence is determined in work [8] experimentally). To such density distribution corresponds the distribution of temperature given on fig. 2d. The estimation of temperature by the method of two speeds stated above has given the value of the maximal temperature $T = 1404\,K$, that well corresponds to an estimation $T \approx 1370\,K$, which is resulted by authors of work [6]. On fig. 5 the comparison of results of calculation of a shock wave speeds as the function of distance from a thermal source with experimental data of work [6]. Good concurrence of results of calculation to the experiment gives the basis to consider that this method of temperature estimation gives enough reliable result.

Conclusion

In work an estimation of plasma parameters by independent methods on experimental data about parameters of the shock waves which are taking place through thermal heterogeneity carry out. The formulas allow to calculate speed of a shock wave and time of its passage to honey points of supervision. Comparison of the offered methods to results of experiments allows to hope, that these methods may be successfully used for an estimation of parameters of plasma in various experimental situations.

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Signatures to figures

Fig. 1. Registration of influence of plasma on shock wave distribution at $p = 1.6$ Torr (passing time between registration points, from works [3, 4])

Fig. 2. Time of passage t between points of registration of a shock wave with initial Mach numbers $M_0 = M(x_0) = 2.88$ (a) and temperature T (at rectangular distribution) (b) as functions of current density j.

a) Circles - experimental data [4](fig. 1), all curves - calculation under the formula (2) (continuous curve - the temperature was calculated under the formula $T_b \approx cT_0\varphi$ at $c = 1.7$, the top dot curve - at $c = 1.6$, bottom - at $c = 1.8$). A dotted line - calculation under the formula (2) at which the temperature was calculated under the formula $T = (T + T_0)c_b\varphi$. Squares - calculation on (2), the temperature is determined on relative amplitude of a signal, rhombuses - calculation under the formula (2), the temperature was estimated with use of experimental data about time of passage of a shock wave [4].

b) Continuous curve - the temperature was calculated under the formula $T_b \approx cT_0\varphi$ at $c = 1.7$, the top dot curve - at $c = 1.7$, bottom - at $c = 1.8$, a dot-dash line - calculation under the formula $T \approx (T + T_0)c_b\varphi$. Circles - the temperature was defined on experimental data by [4] decision of the equation $t_{be}(T) = (t_{be})_{\exp}$, squares - the temperature is determined on relative amplitude of a signal, rhombuses - calculation with use of experimental data about time of passage of a shock wave [4].

Fig. 3. Distribution of speed of a shock wave on coordinate (a) and an increment of speed due to passage of spatial heterogeneity (b).

a) Continuous curve - speed of a shock wave $V(x)$ with initial Mach numbers $M_0 = 2.88$, a dot-dash line - speed of a shock wave with same $M_0 = 2.88$, but at movement in a homogeneous environment

b) A difference given on fig. 3à speeds in a point of supervision x_e. The temperature at calculation under the formula (2) was defined: under the formula $T_b \approx cT_0\varphi$ (a continuous curve - at $c = 1.7$, the top dot curve - at $c = 1.8$, bottom - at $c = 1.6$), under the formula $T \approx (T + T_0)c_b\varphi$ (dot-dash line), on experimental data of work [4] at $p = 1.6$ Torr on time passages (circles) and on change of amplitude of a signal (squares).

Fig. 4. Dependence of temperature on density of a current at passage of a shock wave through the category in argon (a) at $p = 30$ Torr and in nitrogen (b) at $p = 10$ Torr. Circles - the temperature was defined by the decision of the equation $t_{be}(T) = (t_{be})_{\exp}$ or calculation with use of experimental data about time of passage of a shock wave [5], squares - the temperature is determined on relative amplitude of a signal by [5].

a) Continuous curve - the temperature was calculated under the formula $T_b \approx cT_0\varphi$ at $c = 1.15$, the top dot curve - at $c = 1.2$, bottom - at $c = 1.1$, a dot-dash line - calculation under the formula $T \approx (T + T_0)c_b\varphi$.

b) Continuous curve - the temperature was calculated under the formula $T_b \approx cT_0\varphi$ at $c = 2.1$, the top dot curve - at $c = 2.2$, bottom - at $c = 2.0$, a dot-dash line - calculation under the formula ($T \approx (T + T_0)c_b\varphi$

Fig. 5. Distribution of shock wave speeds speed from density distribution. Points - experimental results of work [6]. A continuous curve - the numerical decision, at $p = 60$ Torr. Linear distribution of density [6].